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Key factors impacting performance of a salinity gradient solar pond exposed to Mediterranean climate

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ABSTRACT

Solar ponds are low cost pools of brine solutions with integrated storage zones that harvest incident solar energy and store it as thermal energy. The current study examined the performance of a salinity gradient solar pond under the Mediterranean climatic condition for ten consecutive months of operation, from October 8, 2014 to July 31, 2015. The presented results are based on the experimental data of a small-scale circular pond, 61 cm in diameter a height of 55 cm, constructed and operated at Middle East Technical University, Northern Cyprus Campus (METUNCC). The study showed the necessity of regular surface washing and having excess undissolved salt at the lower convective zone (LCZ) to maintain the pond stability. The variations in the temperature of the non-convective (NCZ) and lower convective zones (LCZ) are found to be a function of both ambient temperature and solar irradiation (insolation). The variation of the overall pond's temperature strongly follows the changes in ambient temperature while solar insolation directly affects the increase in temperature gradient by depth. During the period of this study, the pond reached the highest average temperature of 48 °C in July 2015 while the average ambient temperature for this month was 30 °C.

1. Introduction

Renewable energy sources have been gaining greater importance in the recent years. It is crucial to develop devices and processes to supply energy from non-polluting and renewable energy sources for sustainable developments. The solar pond is an example of such devices that collects solar energy and stores it as thermal energy for a long duration. The first reference to a naturally occurring brine solar pond is attributed to Kalecsinsky in 1902 with his observations of temperatures about 70 °C at a depth of 1.3 m in the Medve Lake in Transylvania (El-Sebaii et al., 2011). Kalecsinsky was the first to record and address the correlation between temperature and salt concentration profiles in ponds. The corresponding theoretical was performed by Weinberger (1964) where an understanding the thermophysical behavior of solar ponds was presented. This was followed by making the first large-scale artificial solar pond for thermal energy storage by Tabor and Matz (1965). Most experimental studies on practical utilization of artificial solar ponds were started mainly around mid-1970s (Norton, 1992). These earlier studies indicated that the temperature in solar ponds may reach up to 70–80 °C implying that the thermal energy from solar ponds can be useful for applications with low-grade energy demands (Sukhatme and Nayak, 2008). One of the most important advantages of solar ponds over other renewable energy sources, such as solar collectors, is their lower investment cost (Sukhatme and Nayak, 2008). Solar ponds are environmentally friendly, and can be used for heating and/or electricity generation. The heat obtained from a solar pond can be converted into electric power even at low temperature values (Bernad et al., 2013). In this regard, organic Rankine cycle engines are

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typically operated using the temperature difference in a solar pond. For applications where the organic fluid fails to operate because of a low temperature difference, thermoelectric generator could be a good candidate to replace ORC engines for power generation (Singh et al., 2012).

The principle of solar ponds is quite simple. In ordinary ponds, the solar radiation reaching the pond is absorbed by water which causes the lower level water to heat up. The heated water has lower density, and thus rises to the pond surface due to natural convection and loses its thermal energy to the atmosphere. In solar ponds, the natural convection is inhibited in order to retain the absorbed heat at the bottom of the pond. The suppression of buoyancy-driven natural convection is done by creating a salinity gradient in the pond and making the water at the bottom denser. Salinity gradient solar ponds typically consist of three layers. The first layer, known as the upper convective zone (UCZ), is located at the top of the pond, and contains the least salinity level. The second layer, whose salinity level increases with depth, is called non-convective zone (NCZ). This layer suppresses the convection and acts as an insulator to prevent the heat from escaping to the UCZ and for maintaining a high temperature at deeper depth. The last layer, made of a saturated salt solution, is responsible for energy storage and is known as the lower convective zone (LCZ) (Zangrando, 1980; Tabor and Weinberger, 1981). The performance of a solar pond decreases with the increase of evaporation rate and decreasing salinity gradient (Ouni et al., 1998).

There have been a number of small-scale experimental studies carried out on salinity gradient solar ponds in different regions of the world under different climatic conditions. Bernad et al. (2013) performed an experimental work to examine the performance of a 50 m^2 solar pond in Spain. According to their findings, the small-scale pond reached a maximum temperature of 75 °C in summer with about 16% of incident radiation available for extraction. Dah et al. (2005) conducted a study on a laboratory scale pond in Tunisia and analyzed the evolution of temperature and salinity profiles in the pond during one month of operation. They attained a maximum temperature of 45 °C having a temperature difference of 23 °C between the bottom and the surface of the pond. Karim et al. (2010) performed an experimental study to analyze and maintain the stability of solar ponds in Tunisia. Using the MATLAB model developed by Jaefarzadeh (2004), Sakhrieh and Al-Salaymeh (2013) investigated the performance of a solar pond under Jordanian climate conditions during two weeks of the operation. Their result indicated that temperature at the LCZ correlated well with the ambient temperature variations. They achieved a maximum temperature of 47 °C when the ambient temperature was approximately 30 °C. Nie et al. (2011) constructed a large-scale shallow salt gradient solar pond using the natural brine of a local salt lake in the Tibet plateau. They observed that the LCZ temperature varied from 20 °C to 40 °C over one year. El-Sebaii et al. (2013) investigated the thermal performance of a shallow salt gradient solar pond under open and closed modes of heat extraction, under Egyptian weather conditions. They concluded that their constructed pond could be used as a heat source for most domestic and low-grade energy demand industrial applications all year-round. Karakilcik et al. (2006) investigated the experimental and theoretical temperature distributions and amount of heat losses within a solar pond in Turkey. They found that the total heat losses from the surface of the pond accounted for more than 85% of the losses, while the losses from the side walls and ground were far less.

Small-scale solar ponds can be useful for investigating the important factors affecting the performance of large-scale solar ponds (Suárez et al., 2014). In particular, small-scale solar ponds can be operated for a longer period because of the lower operation and maintenance cost, and under more controlled conditions compared to large-scale solar ponds. Performance of solar ponds is greatly influenced by climatic factors including the ambient temperature, radiation, wind velocity and relative humidity. The significance of these factors varies with the regions making it imperative to study the solar pond performance under the climate of the different regions of the world. While there have been a number of studies on salt gradient solar ponds in different countries, the performance of a solar pond under the Mediterranean climate (Northern Cyprus), has not been yet well evaluated. Additionally, none of the previous experimental studies fully investigated on the impact of the individual aforementioned factors on the performance of a solar pond in a single study. Northern Cyprus experiences the Mediterranean climate enriched in both solar and wind energy together with relatively high humidity and ambient temperature.

The present study was designed to investigating the performance of a salinity gradient solar pond in a region with high levels of solar radiation and wind energy. Another objective of this study was to provide an understanding of the impact of ambient temperature and solar intensity on the performance and temperature variation in the pond. Furthermore, this study provided a comprehensive set of metrological data including ambient temperature, insolation, wind velocity and relative humidity with a daily time resolution for over one year operation of solar pond. These data would be very useful in understanding the dynamics of solar ponds for long-term operations and for model validation purposes. In fact, the previous experimental investigations rarely provided such all the needed information for modeling studies. Another novelty of the present study was to investigate the practical considerations for improving the salt stability which is a key for the proper operation of the large-scale salinity gradient solar ponds.

A small-scale salinity gradient solar pond was constructed and operated at Middle East Technical University, Northern Cyprus Campus (METUNCC) located in Guzelyurt, Northern Cyprus. The pond has been operating since October 8, 2014 and experimental results have been continually recorded. This study presents the experimental and meteorological data from October 8, 2014 to July 31, 2015 for the operation of the METUNCC solar pond. The performance study of the current solar pond together with the meteorological data can provide the needed information for validating a computational model that can be used for evaluating the performance of large- scale solar ponds under various climatic conditions.

2. Materials and methods

A cylindrical pond (61 cm diameter, 55 cm height and 1.2 cm thickness) was constructed and installed at METUNCC. The pond had three zones, the UCZ (15 L), NCZ (45 L) and LCZ (75 L). Table salt was utilized to make salinity solutions. The LCZ was composed of a saturated (C) salt solution (approximately 280 g/l). The NCZ was made of three equally divided sub-layers (each one 15 L) with 3C/4, C/2 and C/4 concentrations. The UCZ contained fresh water. Six thermometers (2 for each layer) were installed on the pond to monitor the daily temperature variations at 9 a.m., 1 p.m., 5 p.m., and 10 p.m. Temperature recording at other time of the day were performed as needed. The pond was equipped with three sampling valves to withdraw samples from each layer to monitor the salt concentrations. The middle valve was located at the middle of the NCZ. Three inlet ports were also installed on the pond to add proper amount of solutions to each zone during the experiments to compensate for evaporation and sampling losses as well as for surface washing. The inner surfaces of the pond were painted black. The bottom and sides of the pond were initially insulated with a 2.5 cm thick thermal insulator, and the insulation layers were thickened to 5.0 cm after the first three months of the operation to minimize the heat loss from the walls.